International Communications in Heat and Mass Transfer 38 (2011) 1135–1141

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Lattice Boltzmann simulation of mixed convection heat transfer in eccentric annulus ☆

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ARTICLE INFO

Available online 19 May 2011

Keywords:
Lattice Boltzmann method
Curved boundary
Multi-distribution function
Annulus
Eccentricity

ABSTRACT

Mixed convection heat transfer in eccentric annulus was simulated numerically by lattice Boltzmann model (LBM) based on multi-distribution function double-population approach. The effect of eccentricity on heat transfer at various locations was examined at $Ra=10^4$ and $\sigma=2$. Velocity and temperature distributions as well as Nusselt number are obtained. The results are validated with published results and shown that multi-distribution function approach can evaluate the velocity and temperature fields in curved moving boundaries with a good accuracy in comparison with the previous studies. The results show that the average Nusselt number increases when the inner cylinder moves downward regardless of the radial position.

1. Introduction

The lattice Boltzmann method (LBM) is a powerful numerical technique based on kinetic theory for simulating fluid flows and modeling the physics in fluids [1–3]. In comparison with the conventional CFD methods, the advantages of LBM include simple calculation procedure, simple and efficient implementation for parallel computation, easy and robust handling of complex geometries, and others. Various numerical simulations have been performed using different thermal LB models or Boltzmann-based schemes to investigate the natural convection problems [4–6]. The lattice Boltzmann equation (LBE) is a minimal form of the Boltzmann kinetic equation, and the result is a very elegant and simple evolution equation for a discrete distribution function, or discrete population $f_i(x, t) = f(x, c, t)$, which describes the probability to find a particle at lattice position x at time t, moving with speed c_i. With respect to the more conventional numerical methods commonly used for the study of fluid flow situations, the kinetic nature of LBM introduces several advantages, including easy implementation of boundary conditions and fully parallel algorithms. In addition, the convection operator is linear, no Poisson equation for the pressure must be resolved and the translation of the microscopic distribution function into the macroscopic quantities consists of simple arithmetic calculations. In general, there exist three approaches for incorporating the heat transfer effect into the LBGK method in the literature, one is concerned with multi-speed models [7,8] and the other is passive-scalar approach [9] and the last one is double-population models [10–14]. The first approach can particularly deal with density distribution function and introduce additional discrete velocities to obtain macroscopic energy equations and equilibrium distribution which usually include higher order velocity terms. In the second approach, a separate distribution function which is independent of the density distribution function proposed [9] and in the third approach, an independent LBGK equation temperature is introduced in addition to the original distribution function of density. The coupling between the two LBGK equations can be implemented in different ways [15–18]. This type of model is usually adopted in practical application, because the multi-speed approach suffers from severally numerical instability [10] and limits in a rather narrow temperature range and in the passive-scalar approach, the viscous heat dissipation and compression work done by the pressure cannot be taken into account. Therefore, in the present study, a type of double-population model is integrated in the numerical scheme. The geometry of the horizontal annuli is commonly found in solar collector-receiver, underground electric transmission cables, vapor condenser for water distillation and food process. Numerical simulation of natural convection in concentric and eccentric circular cylinder has been studied rigorously in the literatures Moukalled and Acharya [19], Lee et al. [20]. Kuehn and Goldstein [21,22] conducted an experimental and theoretical study of natural convection in concentric and eccentric horizontal cylindrical annuli. Their experimental data is commonly used to validate most of the recent numerical studies. Ho and Lin [23] presented heatlines for steady laminar two-dimensional natural convection in concentric and eccentric horizontal cylindrical annuli with mixed boundary conditions. Glakpe et al. [24] presented numerical solutions for steady laminar two-dimensional natural convection in annuli between concentric and vertically eccentric horizontal circular cylinders. Guj and Stella [25] presented numerical and experimental buoyancy driven flow in horizontal annulus. They studied the effect of the

☆ Communicated by W.J. Minkowycz.

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0735-1933/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.icheatmasstransfer.2011.05.004